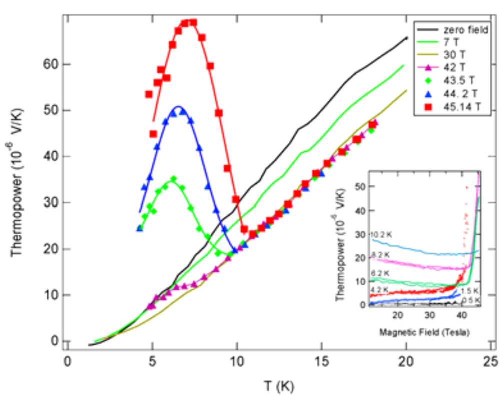
Magneto-Thermodynamics in Low Dimensional Materials above 45 T in the Hybrid Magnet at the NHMFL

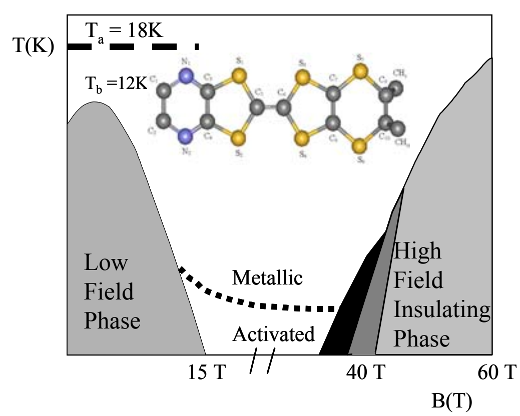
Recently a new high field insulating state above 40 T in a special class of organic conducting materials (the τ-phase) has been discovered by Florida State University researchers in magnetoresistance measurements.[1] Here, a high magnetic field turns a metal into an insulator, that is, the magnetic field “freezes” the electrons, in analogy to the freezing of water to ice.

To obtain a better understanding of this new state of a material, detailed thermodynamic measurements were carried out during the week of June 3, 2002, in the Hybrid magnet to measure the magnetocaloric and thermoelectric[2] effects for fields and temperatures in the range of this high field transition. Researchers wanted to know if the electrons really were frozen out, and if heat was involved in the freezing process.

The experiment involved delicate measurements of temperature and voltage on a tiny organic crystal while the magnetic field was held constant at 45.14 Tesla (a magnetic field almost a million times stronger than the Earth’s magnetic field). The ability to hold the magnetic field at this high value for up to an hour was a critical factor. Moreover, *this measurement at 45.14 T was the first thermoelectric measurement made in such a high, steady-state, magnetic field*.



Thermopower studies of High Field Metal-to-Insulating transition.



Magnetic phases of the τ-type (N-N) materials based on high field measurements.

Researchers were able to determine that the transition from a metal to this new, novel insulating state was indeed a bulk thermodynamic phenomenon in the material, where intense magnetic fields do indeed freeze its electrons.

This research involves:
Principal Investigator: Jim Brooks. Work supported by NSF-DMR-99-71474
2 FSU graduate students supported on this grant and project: D. Graf, E. Jobiliong
2 REU students who participated in the experiment: A. Wade and E. Goetz
2 Postdoctorals: E-S. Choi and K. Storr
External Collaborator: G. Papavassiliou, Inst. Theoretical and Physical Chem., Athens, Greece

[1] Storr *et al.*, cond-mat/0204350, and Phys. Rev. Lett., submitted.
[2] See also, E.S. Choi *et al.*, Phys. Rev. B, **65**, 205119 (2002).
[3] Choi, Brooks, Graf, Jobiliong, Papavassiliou, *et al.*, to be published.

World-Record Research Magnets at the NHMFL

The unique technologies used in these one-of-a-kind high field magnet systems were developed in collaboration with private industry.

45 T Hybrid Magnet System provides the highest continuous magnetic fields in the world.

- Only magnet system in the world providing 45 tesla steady field.
- The closest competitor anywhere in the world provides continuous field less than 40 tesla.
- Available as a user facility for basic research more than 8 hours/day, 8 months out of the year.
- Work is underway to upgrade to 50 Tesla.

The wide-bore 900 MHz system provides unique research capabilities in chemistry and biology.

- The wide-bore 900 MHz system will be the first of its kind in the world.
- It will provide unique science capability for chemistry and biology at ultra-high magnetic fields.
- The wide-bore 900 MHz design provides a path for a low technical risk 1 GHz system.
- A 1 GHz system would provide an opportunity to collaborate with industry in the development of high temperature super-conductors.
- The magnet is currently undergoing testing before being installed in the final cryostat and commissioned for users.

NHMFL Center for Integrating Research & Learning

Enhancing science education locally, throughout Florida, and across the nation

- 15 students representing 13 different universities from 11 states currently participate in the **10th Research Experiences for Undergraduates Program.**
- 124 students submitted on-line applications at http://reu.magnet.fsu.edu
- "The program that you have is leaps and bounds ahead of the REU program that I took part in. I really did not expect the amount of attention given to the needs of the students that we received this summer. I once again want to thank you for the opportunity this summer and I hope that you continue providing students (and teachers) the opportunity to fan the flames of interest in physics and to discover a love for research." Kenneth Purcell, Western Kentucky University (now pursuing Ph.D. at FSU).

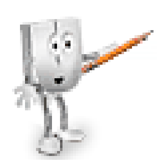
- The **4th annual Research Experiences for Teachers** program received ~60 applications online from teachers nationwide, 18 of whom were accepted for summer 2002.
- 3 participants are **National Board Certified teachers** and 3 teachers are in the process of applying for National Board Certification.
- The RET program is the only one of its kind that works with elementary school teachers and materials created through the program have influenced approximately 2,500 students.
- "This was the most rewarding experience in a summer program that I have ever had. The understanding of the NHMFL that I've gained will be networked to a very large group of people through my students and teaching associates."

Tours and Outreach

- School & Community Outreach: 2500 people; 11,233 contact hours
- Public Tours: 1100 people; 1655 contact hours
- School Tours with Outreach: 270 people; 521 contact hours
- Total people: 3870; Total contact hours: 13,409
- Open House: ~2200

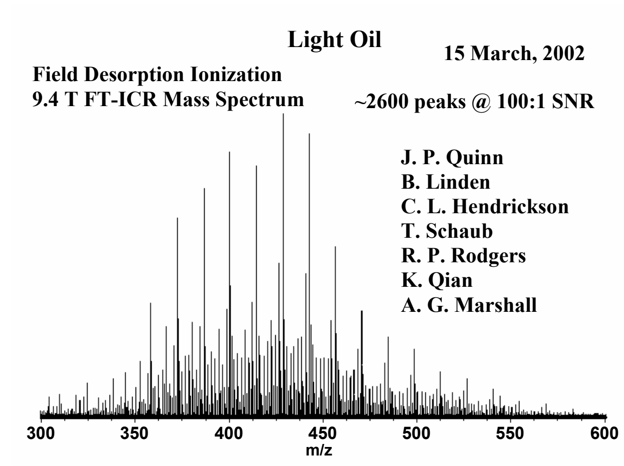
Curriculum Development

- MagLab: Alpha: In ~350 classrooms in Florida.
- *Science, Tobacco & You:* 20 states and approximately 10,000 classrooms; by 4000 teachers in Florida alone. Magnets & You and Optics & You created for elementary workshops.
- Pre/Post Tour Materials

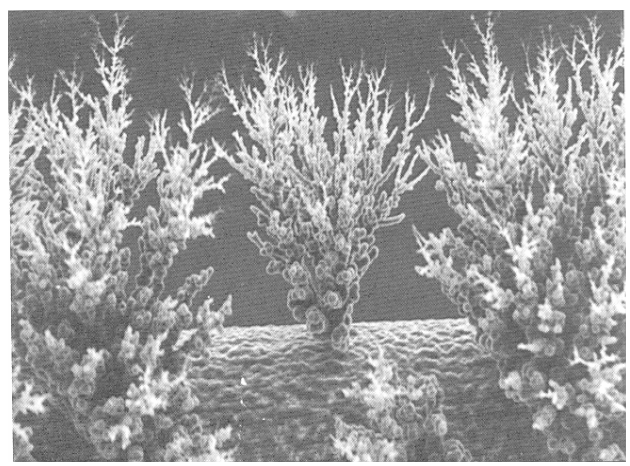


New ICR Techniques Expand Understanding of Light Oil Petroleum and Other Complex Mixtures

The NSF National High-Field FT-ICR Mass Spectrometry Facility at the National High Magnetic Field Laboratory has succeeded in producing the first high-resolution field-desorption mass spectrum, enabling the separation and identification of thousands of components of complex mixtures (in this case, a light oil petroleum distillate).



A microscopic view shows a wire onto which sharp carbon needles have been grown. A liquid drop containing dissolved chemicals is applied to the wire, after which application of a high voltage produces a very high electric field that pulls an electron off each analyte molecule. The resulting positively-charged ions can then be separated according to their chemical formula ($C_cH_hN_nO_oS_s$).

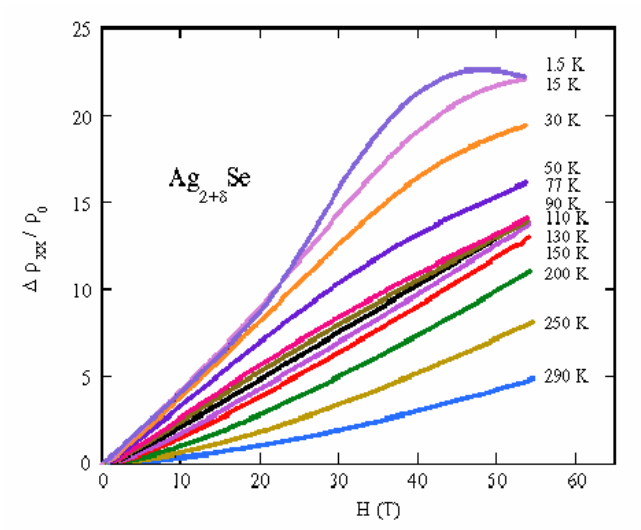


This technique opens access to a wide range of molecules (e.g., the hydrocarbons that constitute >90% of crude oil) not observable by conventional ionization methods. Development is being pursued by NHMFL in collaboration with Bernhard Linden (commercial vendor for the field desorption ion source) and ExxonMobil Research and Engineering (a customer for applications to crude oil characterization).

This research involves:
High Field FT-ICR Mass Spectrometry Facility Director: Alan Marshall
1 undergraduate: Annelie Angstrom, exchange student from Sweden
3 FSU Chem. Dept. Ph.D. candidates: Geoff Klein, Zhigang Wu, and Tanner Schaub
3 Scholar-Scientists (permanent staff): Ryan Rodgers, Helen Cooper, and Christopher Hendrickson
1 technician: John Quinn
1 machinist: Dan McIntosh
External collaborator/sponsor (Dr. Kuangnan Qian, ExxonMobil Research & Engineering Co.)

New Mechanisms for Magnetoresistance

Magnetoresistance is the amount of electrical resistance in a material when magnetic field is applied. Magnetoresistance of metallic films is the fundamental physics underlying state-of-the-art magnetic storage and read-out of information in computers.



In a series of recent experiments, it has been found that a new material, silver selenium (Ag_2Se), shows a remarkably large magnetoresistance when a fraction of a percent of excess silver is added. This magnetoresistance is nearly linear over four orders of magnitude in magnetic field, from 50 gauss to 500,000 gauss (50 tesla), and exhibits an unusual scaling behavior that makes this material particularly attractive as a magnetic field sensor [R. Xu, *et al*., **Nature, 390** (1997) 57 and A. Husmann, *et al*., **Nature, 417** (2002) 421].

Although yet to be understood, there are similarities with the Extraordinary Magneto-Resistance (EMR) materials that consist of microscopic metallic inclusions in a semiconductor matrix, a system that also shows linear magnetoresistance but which saturates at relatively low magnetic fields around one tesla. [G. Aeppli, *et al*., **Nature** News and Views, **417** (2002) 392.] The speculation is that excess silver imbedded silver selenium forms nano-scale inclusions, whose length scale pushes the saturating magnetic field beyond 50 tesla.

If shown to be true by planned future experiments, silver selenium will be the latest example of the utility for intense magnetic fields to probe materials important in nano-science.

Superconductivity in a Layered Magnetic Organic Insulator Induced by High Magnetic Fields

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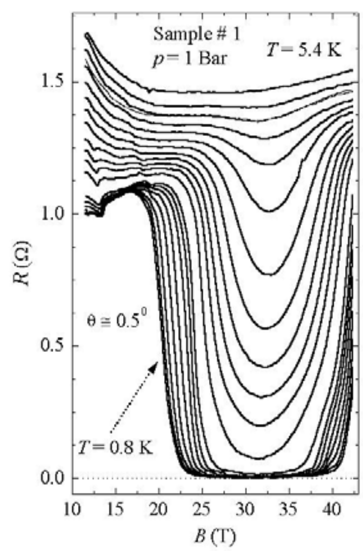
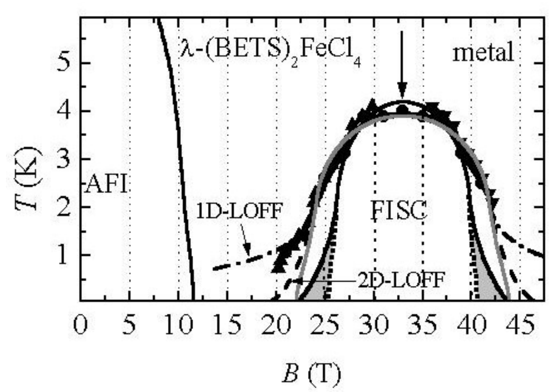
S. Uji, National Institute for Materials Science
H. Kobayashi, Institute for Molecular Science, Japan

The complex interaction between superconductivity (SC) and magnetism is one of the most relevant topics in condensed matter physics. Although SC is suppressed by an external magnetic field and by magnetic impurities, in many new exotic systems magnetic fluctuations have been proposed to be responsible for the superconducting pairing mechanism.

In a few exceptional cases, like in the magnetic organic compound λ-$(BETS)_2FeCl_4$, its inner magnetism is the necessary ingredient for stabilizing a superconducting state with the application of an external field *B*. This system is composed by localized magnetic ions which, when aligned by the field, interact antiferromagnetically with itinerant charge carriers. Eventually, this inner magnetic exchange field can be *compensated* or cancelled by increasing the strength of *B* allowing the condensation of a superconducting state in the presence of an attractive pairing. This situation is illustrated in the figure, where SC emerges for $B \geq 18$ T and although its superconducting transition temperature is only ~ 4.2 K it survives to fields up to 45 T at low temperatures.



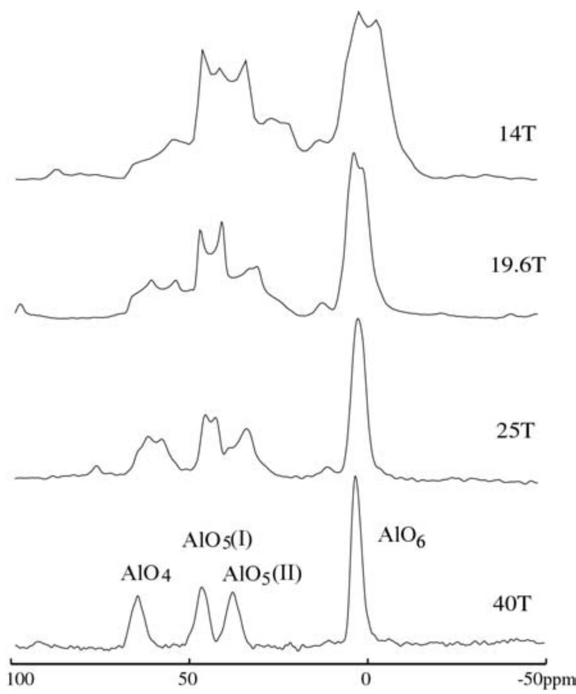
We have determined the field-temperature phase diagram of this field-induced superconducting (FISC) state in the λ-$(BETS)_2FeCl_4$ compound. We have found evidence for strong coupling superconductivity as well as for the so called inhomogeneous Larking-Ovchinikov-Farrel-Fulde (LOFF) superconducting sub-phase.



These studies may lead to artificially-made compounds and wires displaying SC at very large fields. This could have important technological applications in the long term.

High Resolution Solid State NMR at Ultra High Magnetic Fields for Applications in Material Chemistry

The NMR group at National High Magnetic Field Laboratory has obtained the highest resolution spectra for solid state NMR of quadrupolar nuclei. The improved resolution opens new possibilities for applications of solid state NMR in material chemistry using the resistive magnets at the NHMFL. With magnetic fields up to 40 tesla (T) and magic-angle spinning up to 40 kHz, the second-order quadrupolar line broadening can be suppressed resulting in spectral resolution similar to spins-1/2 as illustrated in the spectra of $9Al_2O_3$+$2B_2O_3$ [*J. Am. Chem. Soc.,* **124**, 5634, (2002)].



^{27}Al MAS spectra of $9Al_2O_3$+$2B_2O_3$

Z. Gan
P. Gor'kov
T. Cross
A. Samoson
D. Massiot

J. Am. Chem. Soc.
124, 5634, (2002)

40 kHz Fast Magic Angle Spinning Probe

Varieties of materials such as zeolites, superconductors, and glasses consist of quadrupolar nuclei like ^{27}Al, ^{17}O, ^{23}Na, ^{85,87}Rb, ^{69,71}Ga and etc. Their NMR spectra are dominated by the second-order quadrupolar effect. High magnetic field reduces the second-order effect and increases peak separation through chemical shift resulting in a quadratic gain in spectral resolution. The improved resolution allows the separation of signals from various chemical sites. The resistive magnets at the NHMFL can generate field more than twice as the highest superconductive magnets available and have made such an improvement possible.